



# **NASA Aerospace Flight Battery Systems Program**

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Michelle A. Manzo  
Electrochemistry Branch



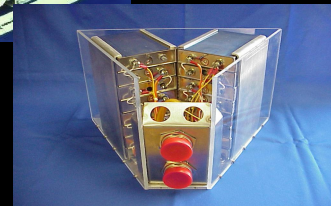
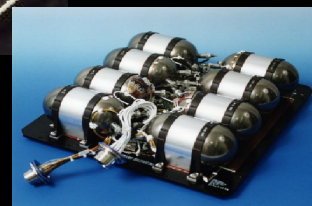
# NASA Aerospace Flight Battery Systems Program Outline

- **Overview**
- **History**
- **Strategic Relevance and Relationships**
- **Benefits and Accomplishments**
- **Current Status**
- **Summary and Recommendations**



## ***NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM***

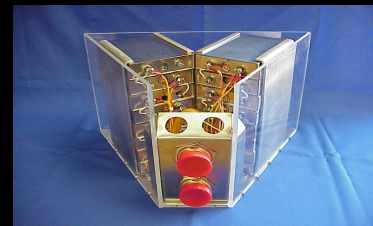
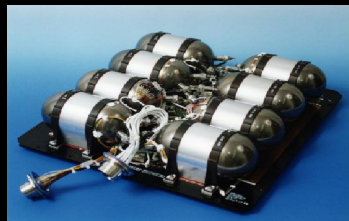
**Unified NASA-wide program, addressing battery related issues. Program goal is to ensure the availability of qualified flight hardware to support NASA's aerospace battery requirements.**



### **Program Objectives**

- **Provide NASA projects with the database and guidelines for technology selection of hardware and processes relating to aerospace batteries**
- **Develop, maintain and provide tools for the validation and assessment of aerospace battery technologies**
- **Disseminate validation and assessment tools, quality assurance, reliability and availability information to the NASA and aerospace battery communities**
- **Accelerate the readiness of technology advances and provide infusion paths for emerging technologies**

# ***NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM***



## **Approach**

- **Maintain current battery technology**
- **Increase fundamental understanding of primary and secondary cells and batteries**
- **Establish specifications, design and operational guidelines**
- **Open and maintain communication lines within NASA and the aerospace community**

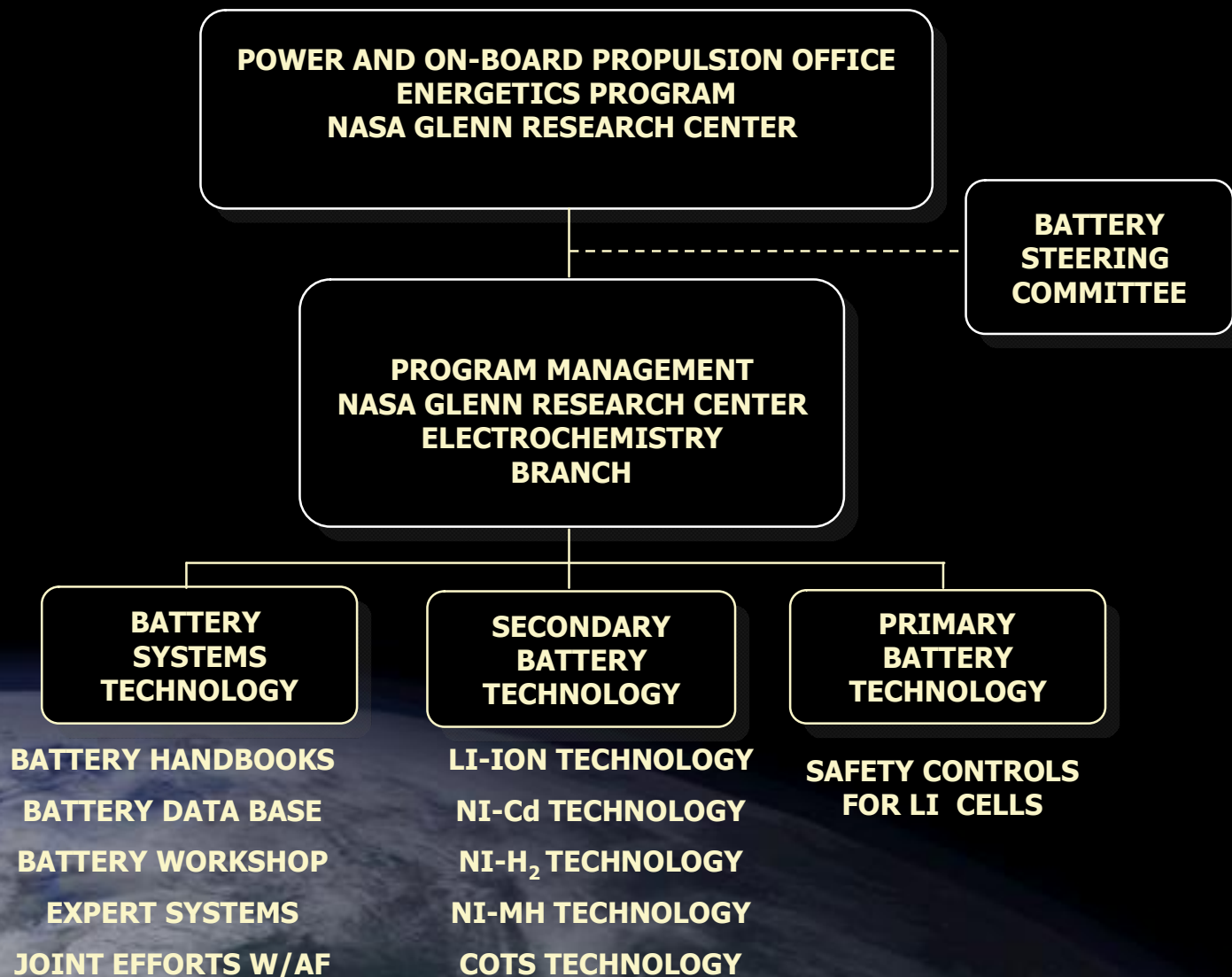
## **Major Players**

- **NASA centers – GRC, GSFC, MSFC, JSC, JPL, LaRC, KSC**
- **AFRL, Navy, Central Intelligence Agency (CIA), National Reconnaissance Organization (NRO), National Air and Space Intelligence Center (NASIC), The Aerospace Corporation**



# ***NASA AEROSPACE FLIGHT BATTERY SYSTEMS PROGRAM***

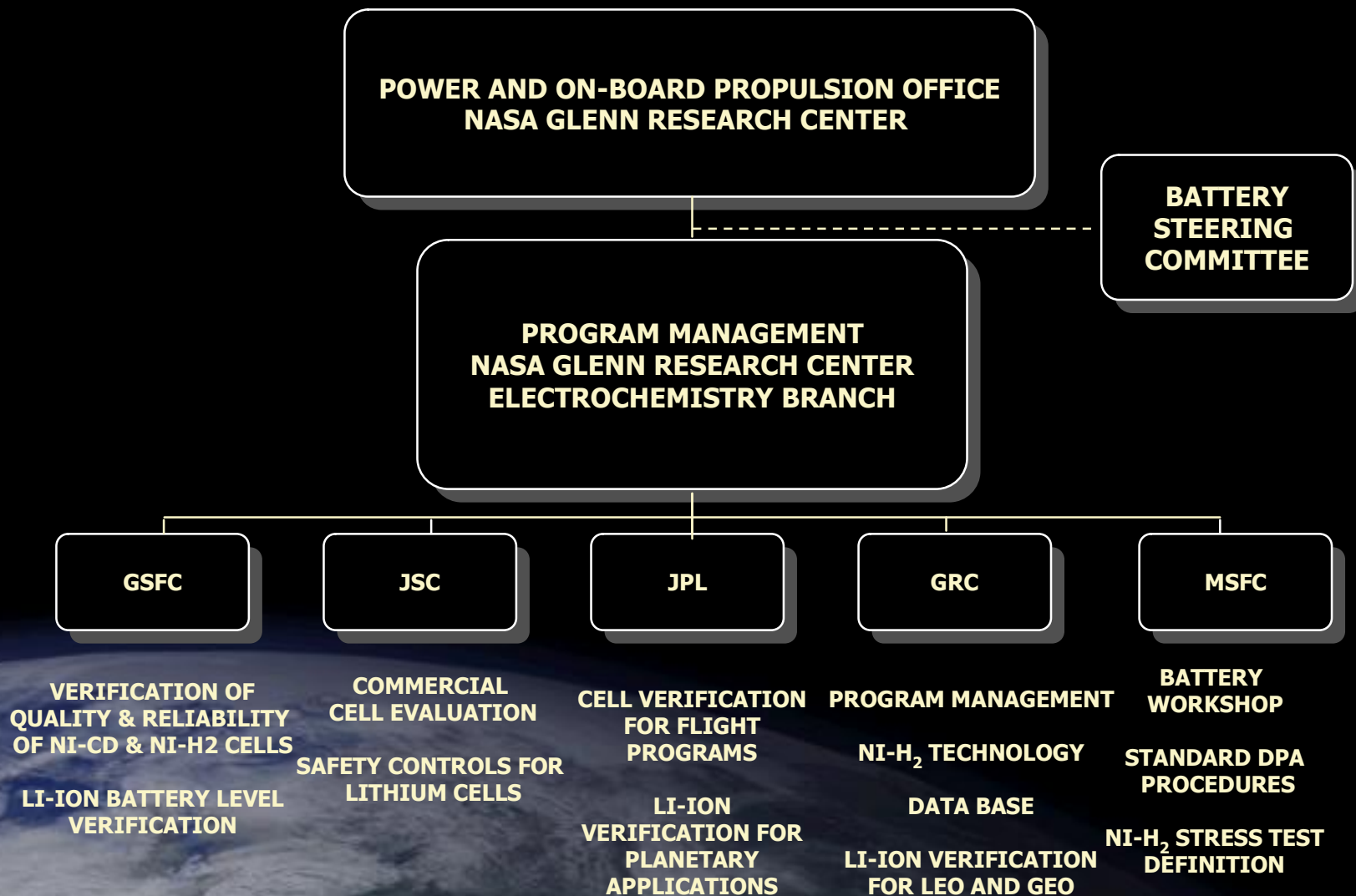
## ***ORGANIZATION – FY05***







## ***TASK RESPONSIBILITIES***





# **NASA Aerospace Flight Battery Systems Program**

## **History – Program Initiation**

**NASA Aerospace Flight Battery Systems Steering Committee formed in 1985**

- **NASA Administrator's concerns relating to battery problems**
- **Address problems that developed over the previous ten years**

**NASA Aerospace Flight Battery Systems Program Plan formulated – extensive coordination between Codes D (Chief Engineer) and R (Research)**

- **Unified NASA-wide approach - involved other government agencies**
- **LeRC assigned management responsibilities**

**Initial objectives :**

- **Improve quality, reliability, safety and performance of flight batteries and battery powered systems**
- **Address needs of the NASA flight programs**
  - **maintain current technology**
  - **develop new technologies to the flight readiness state**
- **Serve as a technology bridge between research and applications**
  - **provide the developmental confidence so that programs may proceed with current up-to-date technology**

***Inexpensive insurance against serious battery related issues on flight programs***



# **NASA Aerospace Flight Battery Systems Program History**

- **1989 - Severe technical problems with NASA Standard Ni-Cd cells – used by nearly all NASA missions → NASA Deputy Administrator – directed Code Q to:**
  - **resolve the continuing performance, quality and reliability problems experienced with space flight nickel-cadmium batteries**
  - **manage and direct the activities to improve the performance, quality, and reliability of flight nickel-cadmium batteries, including means to stabilize and control manufacturing processes**
  - **maintain the battery baseline program consisting of development and issuance of appropriate controlling documentation, including management instructions, handbooks, and specifications to allow orderly procurement of NASA batteries**
- **Program plan revised, funding augmented to address severe issues with NASA standard cells – efforts to establish a NASA standard Ni-Cd cell design**
- **1995 HQ reorganization**
  - **Responsibility for Battery Program shifted from Code Q**
    - **Debate regarding new location – Code X (technology) or Code AE – Chief Engineer's Office**
  - **Technology related functions and management shifted to Code AE**





# **NASA Aerospace Flight Battery Systems Program History**

- **1997 Transition year**
  - **Downsize HQ - Program Management responsibilities shifting to centers**
  - **Battery Program responsibilities transferred from Code AE to Code S (FY98)**
- **1998 – Battery Program and Funding Transferred to Code S**
  - **Part of CETDP program**
  - **No longer had program managers at HQ – program advocates**
- **2000 GRC Realignment – Program Office assumed responsibility for CETDP Program**
  - **CETDP transitioned to Energetics**
  - **Program Responsibilities transferred to Code R**
- **2004 Office of Exploration Systems – Internal Call for Proposals (ICP)**
  - **NOI submitted to refocus and continue program under Technology Maturation**
  - **Full proposal not requested – deemed not an H&RT responsibility**
- **2005 – Final year of funding as a program**
- **2006 – Li-ion Verification (\$500K) funded through Exploration Technology Development Program**

# NASA Aerospace Flight Battery Systems Program Funding History



<b>FY</b>	<b>Budget - \$K</b>	<b>Fund Source</b>	<b>Comments</b>
<b>87</b>	<b>43 + 105</b>	<b>Q</b>	<b>Baseline + Year-end augmentation</b>
<b>88</b>	<b>1200</b>	<b>Q</b>	<b>Full program funding initiated</b>
<b>89</b>	<b>2000</b>	<b>Q &amp; E</b>	<b>Augmentation to address manufacturing issues with Ni-Cd Cells</b>
<b>90</b>	<b>2000</b>	<b>Q</b>	
<b>91</b>	<b>2135</b>	<b>Q</b>	
<b>92</b>	<b>2100</b>	<b>Q</b>	
<b>93</b>	<b>2095</b>	<b>Q</b>	
<b>94</b>	<b>1550</b>	<b>Q</b>	<b>Multiple Fund Sources - Battery Program, Advanced Battery, Test Bed</b>
<b>95</b>	<b>1695</b>	<b>AE</b>	<b>Reorg - Shift to Chief Engineer Office, (debate between AE and X)</b>
<b>96</b>	<b>1797</b>	<b>AE</b>	
<b>97</b>	<b>1500</b>	<b>AE</b>	<b>Transition from AE to S – with funding</b>
<b>98</b>	<b>1500</b>	<b>S</b>	<b>Requirement for crosscutting support across enterprises</b>
<b>99</b>	<b>1500</b>	<b>S</b>	
<b>00</b>	<b>1400</b>	<b>S</b>	
<b>01</b>	<b>1500</b>	<b>R</b>	
<b>02</b>	<b>1400</b>	<b>R</b>	
<b>03</b>	<b>1400</b>	<b>R</b>	
<b>04</b>	<b>1923</b>	<b>R</b>	<b>Partial full cost (Note all prior funding – not full cost)</b>
<b>05</b>	<b>1800</b>	<b>R</b>	<b>Partial full cost</b>



# **NASA Aerospace Flight Battery Systems Program Strategic Relevance to NASA**

- **Crosscutting agency wide program – benefiting all mission directorates**
- **Provides direct linkage between technology development and mission centers**
  - **Identify mission requirements**
  - **Direct technology development**
- **Enables basic aerospace battery focused infrastructure within the agency – supports a core capability and expertise**
- **Provides formal mechanism for addressing aerospace battery related issues**
- **Provides formal mechanism for interactions with other government agencies dealing with aerospace batteries**



# **NASA Aerospace Flight Battery Systems Program Strategic Relationships**

## **Leveraged NASA support**

- **Institutional support from participating centers**
- **Mission/Program support**
  - **MSFC – Hubble Space Telescope (HST), Chandra**
  - **JSC – Mission Office support compliments Commercial-off-the –shelf (COTS) Evaluation**
  - **JPL – Science Mission Directorate - Mars Programs**
    - **Provided Lander batteries for evaluation**
    - **Support for Mars evaluations**
  - **GSFC – Science Mission Directorate Missions**
    - **Representative cell packs for validation**
  - **GRC – International Space Station (ISS), Technology development efforts**
- **Steering Committee**
  - **Forum for communications within NASA**



# **NASA Aerospace Flight Battery Systems Program Strategic Relationships**

- **Other Government Agencies**
  - **Li-ion Verification - CIA, NRO, Air Force**
    - **Respective verification tasks are complimentary**
  - **MOU with the AF for Joint Battery Verification Tasks**
    - **Ni-H<sub>2</sub> CPV Cell Verification, Ni-Cd Storage Tests**
  - **Li-ion Modeling with the CIA**
    - **Li-ion cells for model verification and validation**
    - **Support development of Li-ion model with performance data**
  - **Coordinated test efforts – Navy, NRL**





# **NASA Aerospace Flight Battery Systems Program Benefits**

- **Validated technology available for selection for NASA missions – enable implementation of latest technology advances**
- **Provides support of technology used on near-term and on-going missions – means for NASA to develop “hands-on” experience**
- **Provides basic knowledge base to address battery management and performance issues**
- **Core activity that promotes inter-center, inter-agency communications**
- **Provides venue for formal collaborations**



# **NASA Aerospace Flight Battery Systems Program Benefits**

- **Reviews conducted by the NASA Aerospace Flight Battery Systems Steering Committee**
  - **Battery experts readily available to assess issues related to flight batteries - recent evaluations**
    - **Boeing proposal to use Li-ion Batteries to replace Ni-H<sub>2</sub> batteries on the International Space Station (Spring 03)**
    - **Qualification Processes used to certify commercial-off-the-shelf technologies for use on International Space Station (Spring 04)**
    - **Lithium-ion Battery for Extravehicular Mobility Unit Failure – (July 2006)**

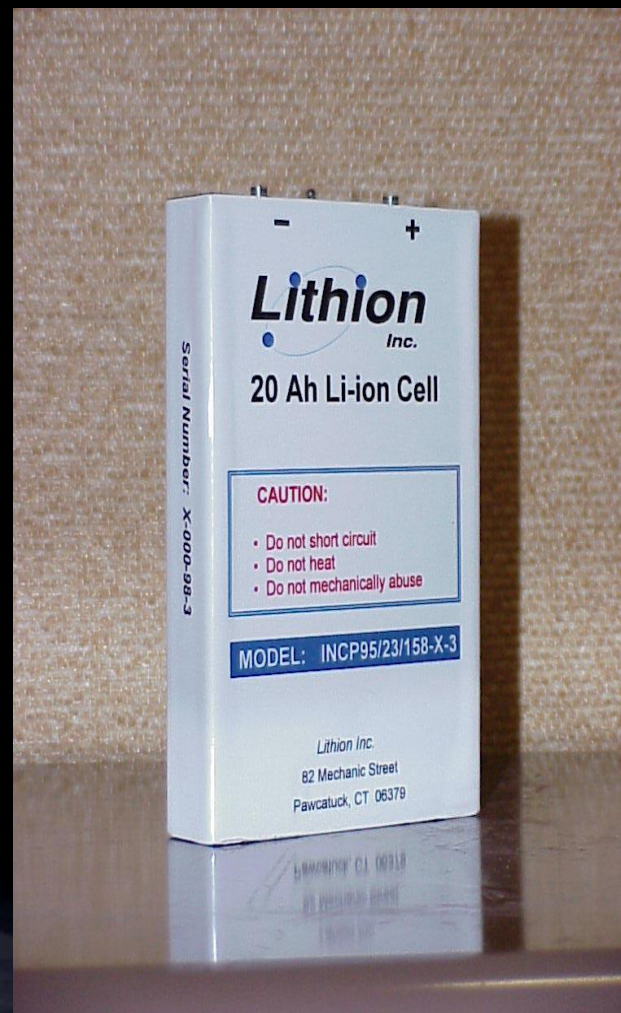
# NASA Aerospace Flight Battery Systems Program Benefits



## Li-ion Validation

*Established mission readiness of Li-ion batteries for Mars missions*

- **Demonstrated excellent life at 100% DOD – prototype versions of Rover and Lander cells**
- **>60% Capacity retained after 2000 cycles**
- **Fade rate increases with higher temperatures and decreases with lower temperatures**
- **Demonstrated >2000 cycles at  $-20^{\circ}\text{C}$**
- **Demonstrated appropriate real-time storage characteristics for prototype Li-ion cells for long duration missions**



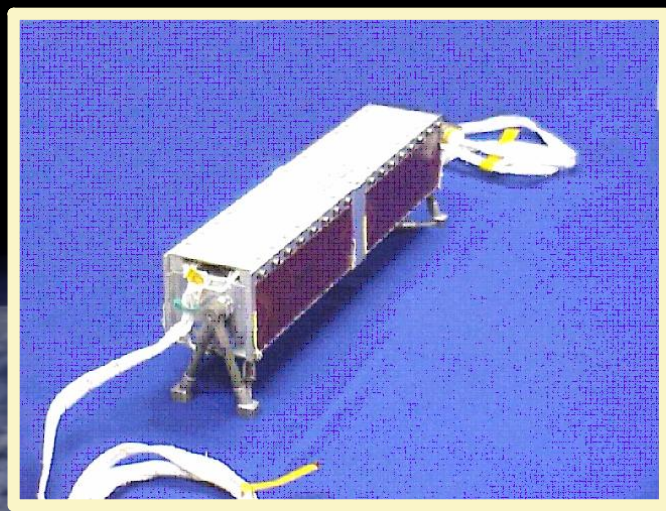




# NASA Missions Benefit from Li-ion Battery Technology



**Performance and validation testing of Li-ion technology performed under the NASA Aerospace Flight Battery Systems Program provided data base that enabled selection of this new technology for Mars 2001 Lander, Mars Exploration Rover, ST5, SDO and LRO Missions**



# NASA Aerospace Flight Battery Systems Program

## Accomplishments

### Nickel-Hydrogen Validation

- **Generated extensive database for the validation of advanced design features for Nickel-Hydrogen**
  - Demonstrated improved performance in cells incorporating NASA technology advancements
  - Design features adopted by industry
  - CPV validation led to cell selection for MGS followed by subsequent Mars missions
- **Generated data base that demonstrated effects of wet/dry storage**
  - Provides missions with an assessment of performance impact related to launch delays
- **Demonstrated performance limitations for CPV (Common Pressure Vessel) cells**
  - <20000 cycles for current design CPV cells vs >40000 cycles for IPV cells







# **NASA Aerospace Flight Battery Systems Program Accomplishments**

## **Nickel-Cadmium Validation**

- **Battery test bed used to validate charge methodology that enabled mission length for Topex to be extended beyond 10 years**
- **Generated extensive database for the validation of Nickel-Cadmium cell technology – used to qualify alternates to NASA standard cells**
- **Enabled implementation of Super™ Ni-Cd technology on Explorer missions**
- **Completed study on Super™ Ni-Cd storage**
  - **Determined Super™ Ni-Cd cells do not require active storage techniques – simplifies pre-launch operations**
- **Demonstrated radiation tolerance of Super™ Ni-Cd for deep space applications**



# **NASA Aerospace Flight Battery Systems Program Accomplishments**

## **Li-BCx Primary Battery Validation**

- **Developed flight approved version of Li-BCX cell that eliminates the need for a waiver for flight approval - earlier versions of the cell were not two fault tolerant**
- **Expanded its operational limits:**
  - **Temperature from  $-40^{\circ}\text{C}$  to  $+72^{\circ}\text{C}$  to  $-65^{\circ}\text{C}$  to  $99^{\circ}\text{C}$**
  - **Vibration capability to 30.7 grms max and  $1.2 \text{ g}^2/\text{Hz}$  max.**





# **NASA Aerospace Flight Battery Systems Program Accomplishments**

## **Commercial-Off-The Shelf Technology Validation**

- **Generated extensive test database evaluating the performance characteristics of commercial off the shelf Li-ion, Ni-MH and Ni-Cd cells**
  - **Provided background and reference source that allowed flight of Li-ion cells on following applications: Canon camcorder, IBM Thinkpad laptop, Noise Suppression Headset, MDU (Radiation Dosimeter), Clio PDA**
  - **Provided background and reference source that led to use of Ni-MH for the following applications: X38 Avionics, REBA, EVA Battery Assembly, EHIP EMU Helmet light, PGT drill battery.**
  - **Readily available database on COTS cells enabled timely cell/battery selection for fast turn around return to flight applications**



# **NASA Aerospace Flight Battery Systems Program**

## **Current Status**

- **Battery Program no longer exists – FY05 last year of funding**
- **Outside of mission specific battery support, the Exploration Energy Storage Technology Development Project is the only agency funded battery technology effort – none in Science Mission Directorate, Space Operations Mission Directorate, or Aeronautics Mission Directorate**
- **Exploration Energy Storage Technology Development Project**
  - **Absorbed portions of Li-ion Verification Program**
  - **Provides minimal funding for Center Representative support**
  - **Focused on Li-ion technology and Exploration mission requirements**
    - **Heritage systems are not supported**
    - **Primary battery chemistries are not addressed**



# **NASA Aerospace Flight Battery Systems Program**

## **Current Status**

- **The current Agency philosophy that requires mission directorate specific support not effective for aerospace batteries**
  - **Limits NASA's position and selection pool to what a specific mission can afford to evaluate/qualify**
  - **Does not ensure NASA's readiness and ability to fly the newest, most effective technologies**
- **Without the Battery Program ...**
  - **NASA will have limited insight and hands-on experience with emerging Li-ion technology and will lose the capability to maintain mature technologies**
  - **Supporting battery test programs at centers will be terminated – this includes long term life tests**
  - **Formal communications will not be supported**
    - **Battery Workshop, handbooks, guidelines documents**





# **NASA Aerospace Flight Battery Systems Program**

## **Current Status**

- **Current efforts to secure continued support for this effort**
  - **Proposal to the NESC to address battery related issues facing upcoming NASA missions**
    - **Loss of source for teflon material used in electrodes for Ni-H<sub>2</sub> cells – HST, ISS, JWST**
      - **Requalification of cells with replacement materials**
      - **Stockpiling of materials made with qualified material**
    - **Wet life of batteries stored due to launch delays – HST, ISS**
    - **Standards for Li-ion Batteries**
    - **Battery Procurement Guidelines**
    - **Li-Ion Source Materials**



# **NASA Aerospace Flight Battery Systems Program**

## **Current Status**

- **Current efforts to secure continued support for this effort - July 21 - Presentation to Chief Engineer's Office and Office of Mission and Safety Assurance**
  - **Recommend development of an Agency strategy to support and enable the continuation of the NASA Aerospace Flight Battery Systems Program**
  - **Establish base program support from traditional support areas – Chief Engineer's Office, Safety and Mission Assurance Office**
  - **Provide additional Mission Directorate specific support as need and funding availability arise**
    - **Flight programs leverage NASA Aerospace Flight Battery Systems Program**



# **NASA Aerospace Flight Battery Systems Program Summary & Recommendations**

- **Maintain basic structure and function of the NASA Aerospace Flight Battery Systems Program**
- **Program addressing generic technology validation and support provides NASA with the experience base to effectively deal with issues as they arise**
- **Refocus program to prioritize and directly align technology validation and support efforts with Mission Directorates and Mission Support Offices**



# NASA Aerospace Flight Battery Systems Steering Committee Membership/Battery Program Support

Center/Agency	Representative
NASA GRC	Michelle Manzo, Concha Reid, Barbara McKissock, Tom Miller
NASA GSFC	Gopal Rao, Leo Lee
NASA JPL	Subbarao Surampudi, Ratnakumar Bugga, Marshall Smart
NASA JSC	Eric Darcy, Judy Jeevarajan
NASA KSC	David Olsen
NASA LaRC	Guillermo Gonzalez
NASA MSFC	Jeff Brewer
NRL	Chris Garner, Zoila Forgione
NASIC	Larry Ward
US Air Force	Steve Vukson
US Navy	Harry Brown
US Government	Joe Stockel, Scott Verzwylt, Kathy Steele
Aerospace Corporation	Warren Hwang, John Halpine